ESTEP 2025 Annual Event
28-30 October 2025
Udine (ITALY)

How decarbonisation, digitisation and circular solutions forge the sustainable European steel future?

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement N° 101070046

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ALCHIMIA: Federated and Continual Learning for Sustainable and Competitive Steelmaking

ESTEP European Steel Technology Platform
DIGIMET
DANIELI AUTOMATION
UNIVERSITÀ DEGLI STUDI DI UDINE
HIC SUNT FUTURA

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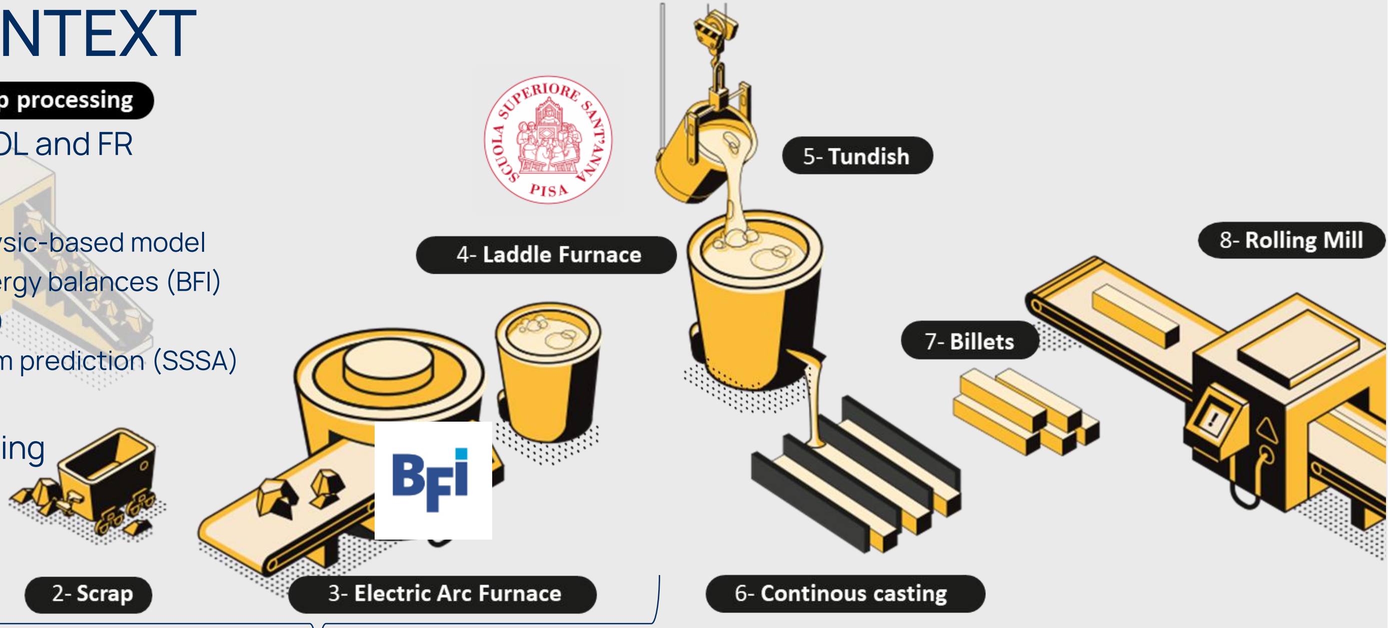
PROJECT CONTEXT

- **3 CELSA plants**: BCN, POL and FR
- 2 modelling approaches:
  - **Analytical models**: physic-based model
    Dynamic mass & energy balances (BFI)
  - **Neural models** (FFNNs)
    Temperature & Chem prediction (SSSA)
- **Goal**
  Enable cross-plant learning without data sharing

SMARTER, GREENER PROCESSES VIA DISTRIBUTED AI



ALCHIMIA

Products

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WHY FEDERATED AND CONTINUAL LEARNING?

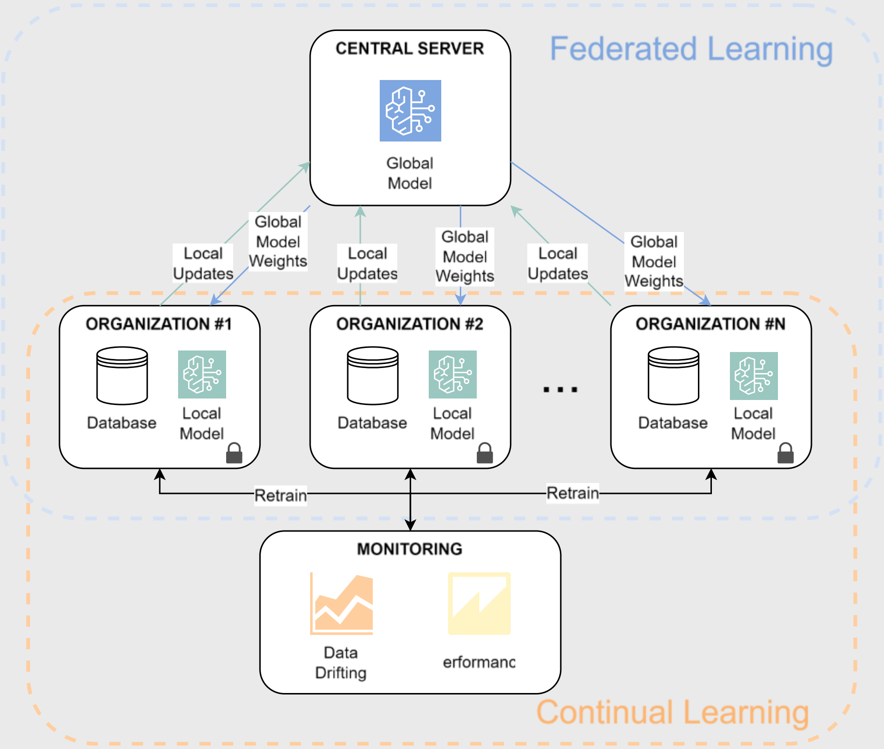
- **Federated Learning** (FL)

  Local training + Global aggregation

- **Continual Learning** (CL)

  Monitors model drift + Automatic retrain

- **Together FL + CL**
  - Enable **cross-plant collaboration** while preserving privacy and data ownership
  - **Maintain model performance** in evolving industrial conditions
  - Build adaptive and trustworthy systems for **long-term solutions**



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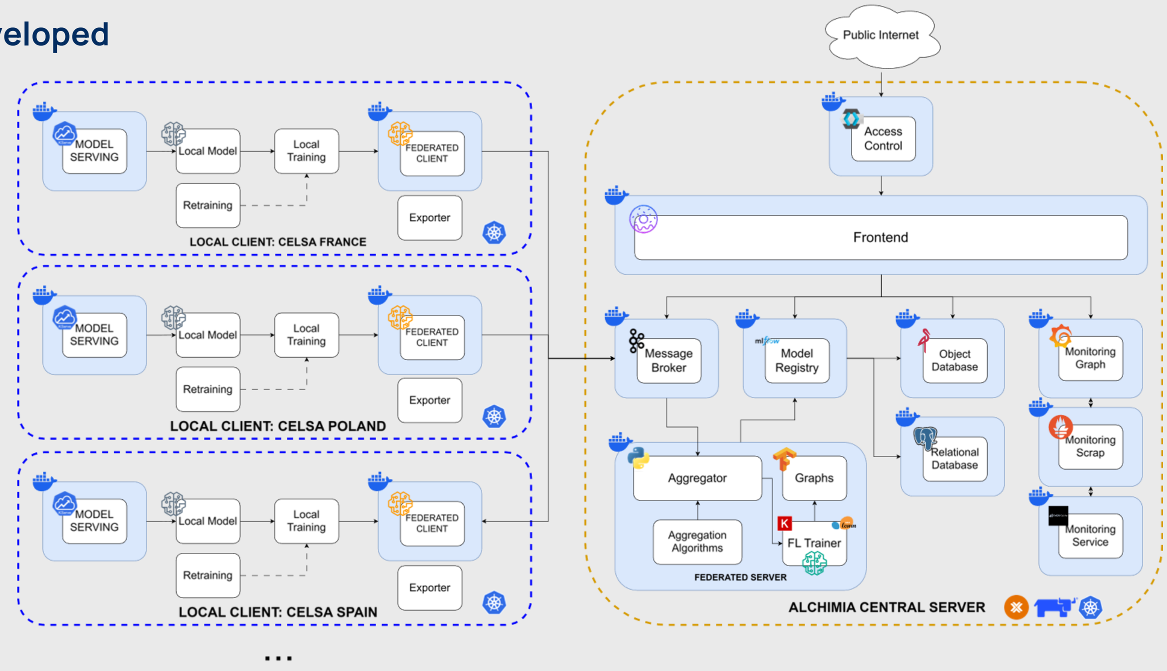
CELSA USE CASE

- 2 Processes x 3 Plants = **6 models developed**
  - EAF Dynamic Process Model
  - Ladle Furnace Neural Model
- **Unified data schema & ETL** pipeline
- **Federated Learning (FL)**
  - Local training on each plant's data
  - Model weights → securely sent → ATOS central server
  - Global aggregation (FedAvg) → updated model redistributed
- **Continual Learning (CL)**
  - Real-time monitoring of model performance
  - Automatic drift detection (e.g., scrap mix, sensor drift)
  - Trigger local retraining → updated weights → federated update
  - Extends model lifespan & stability; reduces maintenance cost



FEDERATED LEARNING ON ANALYTICAL EAF MODELS

- **Model type**: Analytical mass-energy balance model for Electric Arc Furnace (EAF) developed by BFI
- **Objective**: Evaluate whether EAF model can be jointly optimized via FL without sharing plant data
- **Clients**: CELSA Plant 1 (187 heats), CELSA Plant 2 (60 heats), CELSA Plant 3 (108 heats)
- **Shared elements**: Local model parameters (efficiency factors, energy terms)
- **Method**:
  - Iterative **least-squares optimization** per plant → **Parameter aggregation** on ATOS server
  - Tested different **MAX_NFEV** settings and **weighting strategies** (simple, weighted, inverse weighted)
- **Findings**:
  - **Limited improvement over local models** (heterogeneous data)
  - While 2 plants benefited; the third diverged (sensor differences, noise)
  - **Inverse weighting** during aggregation gave best results
- **Key takeaway**:

  FL requires harmonized datasets and consistent operating regimes

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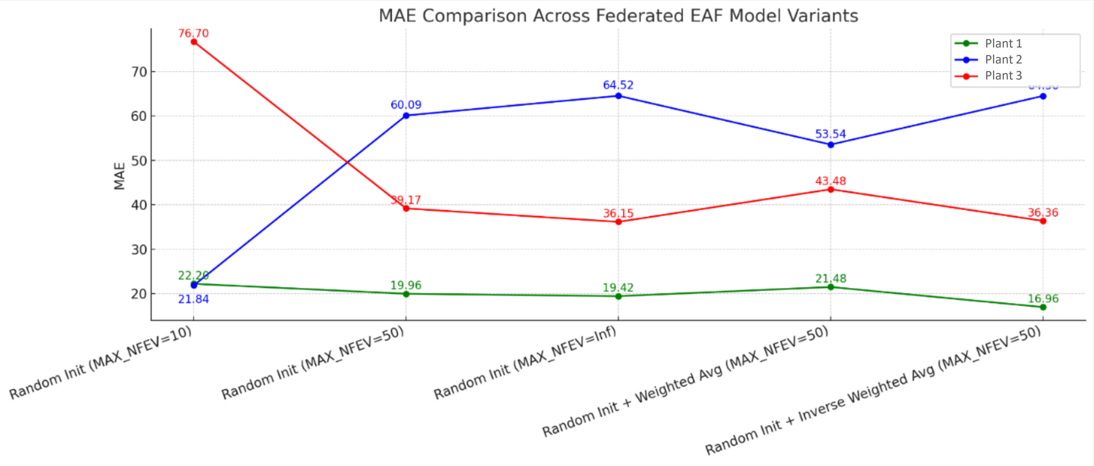
FEDERATED LEARNING ON ANALYTICAL EAF MODELS

- Baseline MAE values for the local models:
  - MAE PLANT 1 = 16,50
  - MAE PLANT 2 = 15,95
  - MAE PLANT 3 = 21,62
- **MAX_NFEV** Maximum Number of Function Evaluations
- PLANT 2 is the smaller plant with most noisy dataset which requires more steps to converge



- **Findings**:
  - **Limited improvement** over local models (heterogeneous data)
  - Plants 1 and 3 show a shared improvement trend, suggesting that they operate within **compatible ranges**
  - Plant 2 tends to perform worse when the other clients improve (sensor differences, distinct operating curves)
  - **Inverse weighting** during aggregation gave best results
- **Key takeaway**:

  FL requires harmonized datasets and consistent operating regimes

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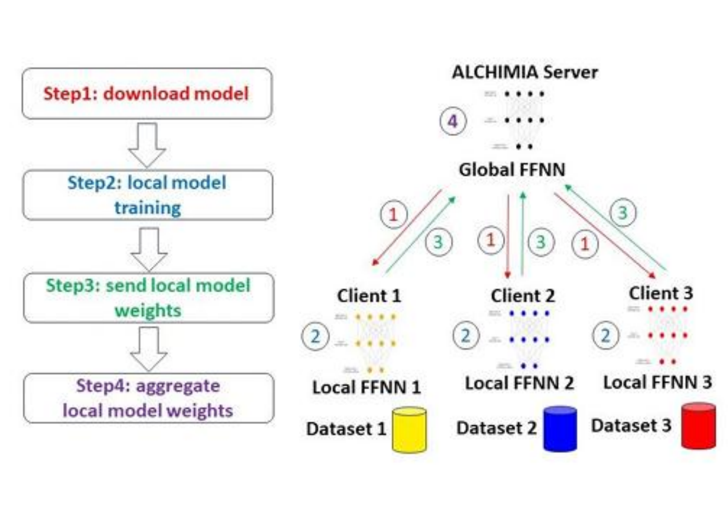
EXPERIMENTS ON NEURAL MODELS (LF)

- **Model type**: Feed-Forward Neural Network (FFNN)
- **Objective**: Predict final steel temperature & chemical composition
- **Clients**: CELSA France, CELSA Spain (BCN), CELSA Poland (PL)
- **Shared elements**: Model weights (privacy-preserved) – no raw data exchange
- **Method**:
  - Local training → send weights → Central **aggregation** → Update global model → **Redistribute**
  - Continual Learning monitors drift & **retrains** automatically
- **Findings**:
  - Global model **outperforms** all local models (MSE ↓ ≈15%)
  - **Strong generalisation** across plants and operating conditions
  - **Stable performance** maintained via Continual Learning
- **Key takeaway**

Federated neural models are more adaptable to plant variability than analytical ones



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INDUSTRIAL INTEGRATION & ACKNOWLEDGEMENTS

- Full integration under development - **Validation phase Q4 2025**
- Towards "**AI-ready plants**": secure, self-learning systems
- **Framework reusability** for other process industries
- **Technology developed** by EVIDEN (ATOS) team:
  - Carmen Perea - carmen.perea@eviden.com
  - Raquel Lazcano - raquel.lazcano@eviden.com
- **Modelling contributions** by BFI & SSSA:
  - Petri Kannisto - petri.kannisto@bfi.de
  - Stefano Dettori - stefano.dettori@santannapisa.it
- **Industrial validation** by CELSA Group
  - David Blazquez – david.Blazquez@gcelsa.com
- Horizon Europe project **ALCHIMIA** – Data and decentralized AI for Green Metallurgy.

Thank you!